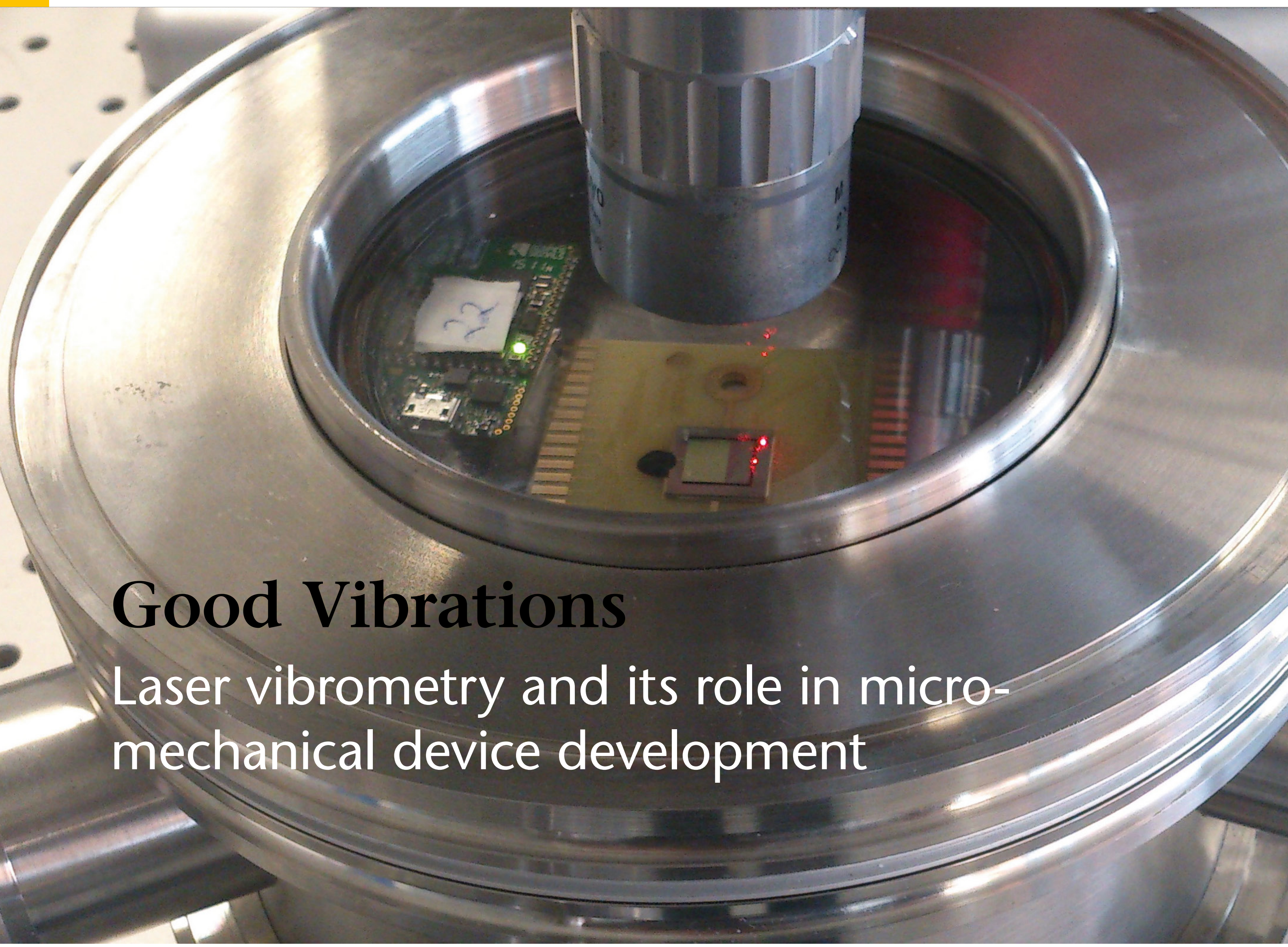

Good Vibrations

Laser vibrometry and its role in micro-mechanical device development

Microelectromechanical systems (MEMS) devices are fabricated using semiconductor-based micromachining techniques, and use electrostatic, piezoelectric, thermal, or magnetic methods to control a micron-scale movable component. Billions of MEMS sensors and transducers have been produced annually since the early 1980s for all aspects of everyday life and are to be found, for example, in vehicles (inertial and pressure sensors), consumer devices (microphones and accelerometers), and digital projection systems (optical micromirrors).

Source: Polytec InFocus 2014 | www.polytec.com

Established with a mission to support industry and academia in driving research to market, the Tyndall National Institute is one of Europe's leading research centers in Information and Communications Technology (ICT) research and development, and the largest facility of its type in Ireland. Tyndall has a large R&D activity focussed on the development of MEMS devices, primarily for industries spanning electronics, medical devices, energy and communication. As part of this activity, non-destructive optical characterization techniques are routinely used for high-resolution, static and dynamic characterization of such structures.

The article introduces the Polytec laser vibrometry facility at Tyndall, and illustrates its use in two applications, namely radio frequency (RF) MEMS for telecommunications, and piezoelectric MEMS cantilevers for energy harvesting.

HARDWARE

Our laboratory is equipped with a 30MHz Polytec MSA-400 with lenses ranging from 1X to 50X, mounted on a TS-140 (Table Stable Ltd.) active anti-vibration table for high-precision analysis, Figure 1. The system is also fitted with a custom-built, 150-mm diameter vacuum chamber with a glass lid and interfaced to an Edwards TY1A12311 turbo pump. The chamber contains an Olympus V101-RM ultrasonic transducer for excitation and an AXL345 accelerometer for chamber motion sensing, as well as several feedthroughs for electrical interfaces. A Falco Systems WMA-300 voltage amplifier supplies the high voltages typically required for MEMS characterization. The system facilitates complete topographical, in-plane and out-of-plane analysis of MEMS structures at pressures varying from below 0.01 mbar to atmospheric.

RF-MEMS

RF MEMS components, such as switches, resonators and varactors, use electrostatic actuation to change the position of a micron-scale, mechanical element suspended over a transmission line, thereby altering the properties of that line and the circuit in which it is embedded. RF MEMS devices exhibit superior RF performance, are small and lightweight and have a high integration capability. They are promising candidates for use in applications such as phase shifting circuits, radio front-ends, impedance matching units and reconfigurable antennas. ►

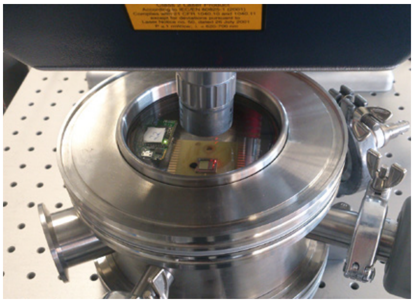

Figure 1:
Left: Polytec MSA-400 at Tyndall, equipped with customized vacuum chamber, active isolation table and high-voltage amplifier.
Right: close-up view of vacuum chamber. A micromachined energy harvesting module is under test; a nearby ADXL345 inertial sensor is used to correlate excitation levels with transducer output.

A major characteristic of a microswitch is the effective mechanical stiffness (k) of the movable electrode, which determines the voltage required to actuate the switch. In general, this effective stiffness is a function of the material properties (Young's modulus and material intrinsic stress) and geometry of the movable electrode. It may be determined experimentally by measuring the mechanical resonance frequency (f) of an electrode of mass m, and using the expression $k = (2\pi f)^2 m$. Figure 2 illustrates mechanical resonance frequency data from 100 µm square aluminum electrodes suspended using three spring types: straight, meander, and spiral springs. It is clear that the resonance frequency (and stiffness) is highly dependent on the geometry of the suspension tethers.

The ambient environment (gas concentration and pressure) around a MEMS device may seriously affect optimal performance and reliability. In Figure 3, the influence of air damping on a simple MEMS cantilever-based resonator is illustrated using a plot of vibration amplitude at various pressure levels. The results clearly show that, in order to ensure a high Q-factor of this resonator, the ambient pressure level in the package must be kept below a certain critical level, which for this particular device is around 1mbar.

PIEZOELECTRIC ENERGY HARVESTING

Energy harvesters convert freely available kinetic environmental energy into electrical energy that can be used to power autonomous low power electrical systems such as wireless sensor nodes (WSNs) in healthcare, structural or machine health monitoring applications. The harvester itself is a mechanical system with a resonance frequency aligned to a spectral peak provided by the application environment. When excited into resonance by its environment, therefore, the harvester acts as a signal amplifier for the external vibration at that particular frequency. The harvester must then be capable of converting the vibration energy into useful electrical energy. Piezoelectric harvesters do this by exploiting the ability of piezoelectric materials to accumulate charges on their crystal faces when mechanically stressed.

At Tyndall we have designed and developed MEMS harvesters with a target resonance frequency below 150 Hz. The devices were

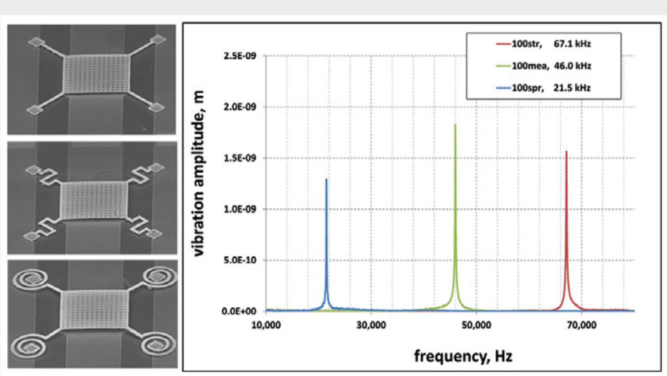

Figure 2: 100 µm square RF-MEMS capacitive switches featuring three different spring designs, along with the measured mechanical resonance frequencies.

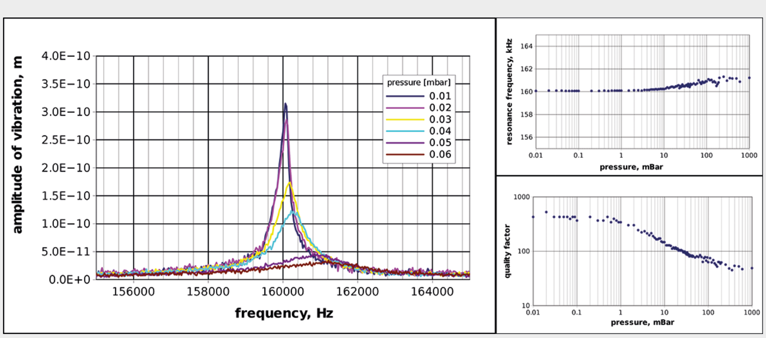

Figure 3: Measured resonance frequency of MEMS resonating cantilever versus pressure (left) and corresponding characteristics of the resonance frequency and mechanical quality factor.

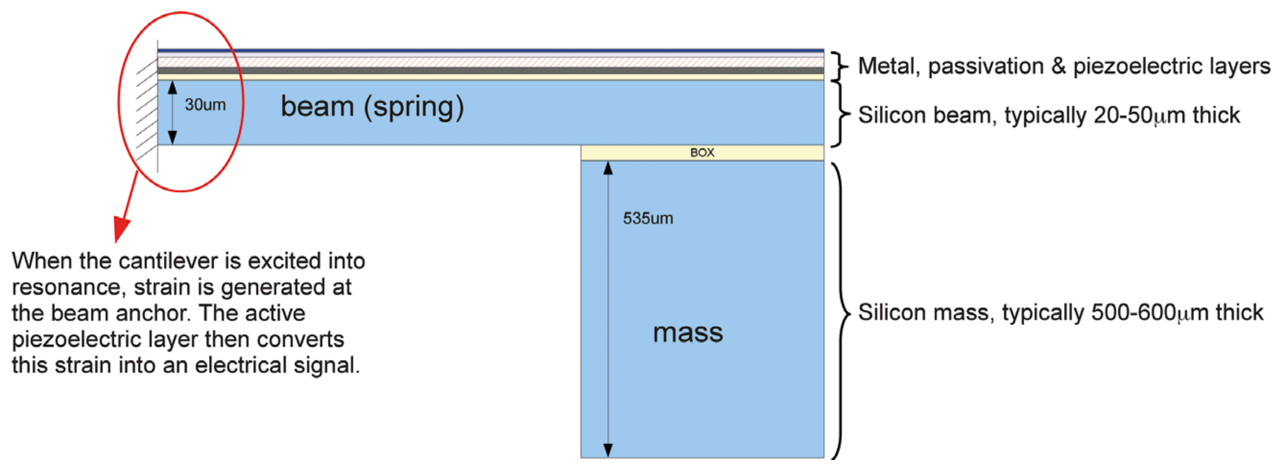

Figure 4: Schematic showing the cross-section of a silicon-based piezoelectric energy harvester.

fabricated using a combination of bulk and surface silicon micromachining technologies. Figure 4 shows, in cross-section, the profile of a cantilever-type, silicon-based harvester. In order to achieve resonances below 150 Hz, the beams, which constitute the system spring, must be long (~ 8 mm - 10 mm) and thin (<50 µm). The entire wafer thickness is used to form the mass.

Two of the major challenges facing energy harvesters is their low power output and inherently narrow bandwidth. One approach to addressing these limitations is to combine the output of multiple harvesters by electrically connecting the devices. This can be achieved using series or parallel (or a combination of both) configurations. Results for three cantilever harvesters, with identical masses but different beam designs, are shown in Figure 5. These devices were designed to resonate at approximately the same frequency. The resonance frequency of the cantilever beams was measured optically using laser vibrometry. The devices resonate between 115 Hz and 118 Hz with displacements of several micrometers. The measurements were taken using the setup shown in Figure 1.

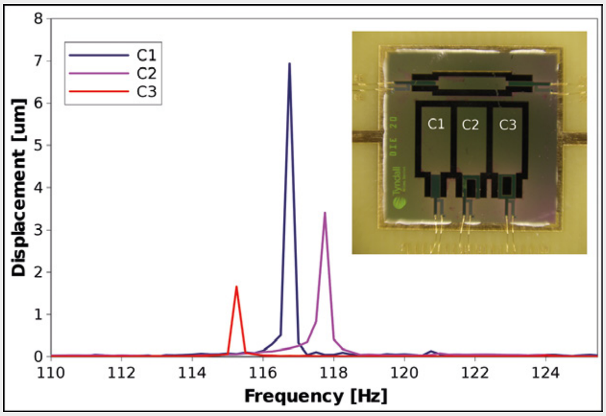

Figure 5: Resonance peaks measured by the vibrometer for three cantilever structures with slightly varying beam designs.

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